IEEE 1393 SPACEBORNE FIBER OPTIC DATA BUS
A STANDARD APPROACH TO ON-BOARD PAYLOAD DATA HANDLING NETWORKS

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ABSTRACT The Spaceborne Fiber Optic Data Bus (SFODB) is the next generation in on-board data handling networks. It will do for high speed payloads what SAE 1773 has done for on-board command and telemetry systems. That is, it will significantly reduce the cost of payload development, integration and test through interface standardization. As defined in IEEE 1393, SFODB is a 1 Gb/s, fiber optic network specifically designed to support the real-time, on-board data handling requirements of remote sensing spacecraft. The network is highly reliable, fault tolerant, and capable of withstanding the rigors of launch and the harsh space environment. SFODB achieves this operational and environmental performance while maintaining the small size, light weight, and low power necessary for spaceborne applications. SFODB was developed jointly by DoD and NASA GSFC to meet the on-board data handling needs of Remote Sensing satellites. This jointly funded project produced a complete set of flight transmitters, receivers and protocol ASICs; a complete Development & Evaluation System; and, the IEEE 1393 standard.

What is SFODB?

SFODB is a highly reliable, fault tolerant fiber optic network designed specifically to meet the harsh thermal, mechanical, and radiation environments of aerospace remote sensing applications requiring small size and low power dissipation. SFODB implements the IEEE 1393-1999 Spaceborne Fiber Optic Data Bus standard that defines an open, software configurable, redundant ring architecture with commercial ATM telecommunications interface compatibility.

The SFODB network is implemented as a ring of up to 127 FBIU data nodes interconnected by a fiber optic Physical Plant with a CFBIU node for network configuration and control.

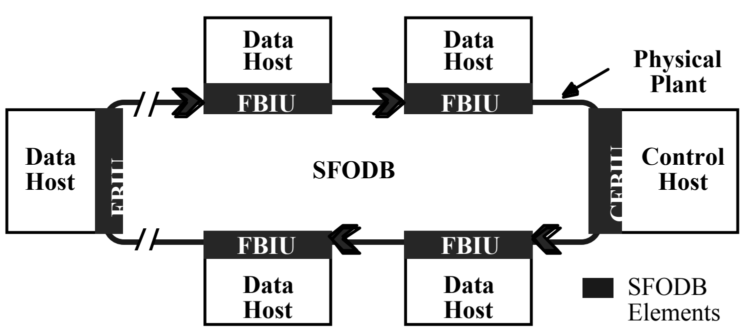
The **Physical Plant** contains the passive elements of the SFODB network; i.e., the fiber optic cables and connectors.

The **FBIU**, or **F**iber-optic **B**us **I**nterface **U**nit, provides the data handling functions required to transmit data onto the network and receive data from the SFODB network

The **CFBIU**, or **C**ontrol **F**iber-optic **B**us **I**nterface **U**nit, provides the configuration, control and status monitoring interface to the SFODB network.

SFODB data transfer can emulate a Connection Switch, Packet Switch or Token Passing protocol. All three protocol emulations can be in operation on the network simultaneously.

The network has an additional Bandwidth Reuse feature that allows the network to operate in a segmented ring configuration. This feature allows a user to multiply the data handling capacity of the SFODB network by the number of ring segments implemented.



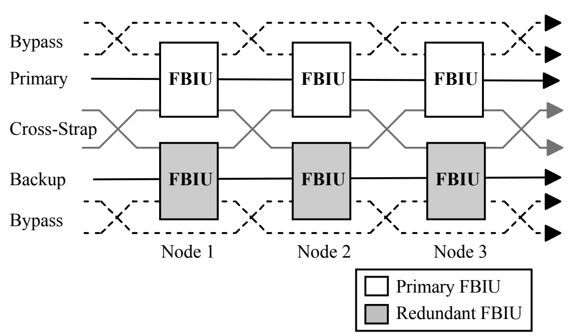
SFODB Performance Summary

Architecture Redundant, Cross-Strapped Fiber Optic Ring with Passive Bypass
Standard Protocol IEEE 1393-1999
Node Capacity 127 Transmit & Receive Nodes
Scaleable Data Rate 200 Mbps to 1 Gbps Node-to-Node and Multi-Gbps Network Capacity with Bandwidth Reuse Feature
Radiation Hardness >100K Rad- Si Total Dose
Node BER $<10^{-13}$ Non-Solar Flare
$<10^{-11}$ Max Solar Flare
Fiber Optic Technology Rad-Hard 1300 nm, 100/140 µm Multimode Graded Index Fiber

Network characteristics

Physical layer characteristics

The baseline configuration for the SFODB network is a redundant, cross-strapped, serial ring with a passive optical bypass feature. The network is capable of supporting up to 127 FBIUs and a CFBIU with a maximum node-to-node spacing of 100 meters.
The Media Dependent Physical Layer is characterized by multimode, graded index fiber with laser diode transmitters and PIN diode receivers operating at an optical frequency in the 1300 nm range. Although multi-fiber cable, multi-pin connectors and specific termini are recommended for inter-operability, the user is free to select a different cable interconnect scheme.

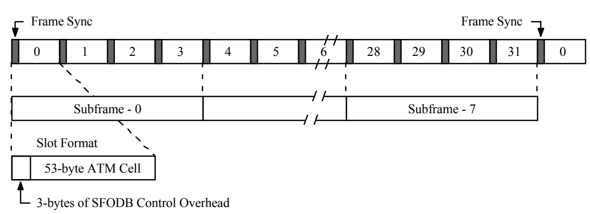


The Non-Media Dependent Physical Layer is characterized by a continuous transmission, serial communications mode. Data is encoded using 8B/10B symbol encoding and frame level synchronization is maintained using the unique K28.5 and K28.7 8B/10B command codes. The encoded symbols are transmitted serially using direct modulation digital On/Off signaling. The SFODB supports a selectable data throughput rate of 200 Mbps to 1 Gbps which equates to an encoded bit rate of 300 Mbps to 1.458 Gbps including ATM Headers and SFODB overhead.

Data link layer characteristics

The Data Link Layer services are provided by the protocol processing elements of the FBIU and CFBIU. These services include the Data Host-to-FBIU and FBIU-to-Data Host data transfer services, the ATM Cell formatting services, the SFODB media access services and the CFBIU Latency Adjust Buffer services.

Transfer of data between Data Hosts on the SFODB ring is accomplished using a simple fixed length 32-Slot, TDMA frame format. Each of the 32-Slots are a fixed 56 bytes in length and contain a standard 53-byte ATM Cell and 3 bytes of SFODB control overhead. There is a deterministic delay around the ring equal to one, two or three frames depending on the number of FBIUs and the distance between the FBIUs in a particular network configuration. This deterministic delay is maintained by a Latency Adjust Buffer (LAB) within the CFBIU that compensates for FBIU quantity and spacing variations and insures that an integral number of Frames is rotating on the ring.



Network bandwidth can be dedicated to an FBIU using the Dedicated Transmit Slot process or shared between multiple FBIUs using the Token Arbitrated process. Both processes transmit data in a broadcast mode. Data delivery can be connection oriented using the Dedicated Receive Slot process or packet oriented using the ATM Header Address process.

The transfer of an ATM Cell between the FBIU and the Data Host forms the DLL boundary. The Data Host is expected to provide all message layer and higher layer OSI protocol services. In the special case of continuous unformatted data transfer between the FBIU and its Data Host the FBIU can perform the data segmentation and reassembly function normally attributed to the Message Layer.

The following items summarize the key characteristics of the SFODB Data Link Layer.

Data format The SFODB network is capable of transferring continuous, unformatted data and formatted data packets between FBIUs. Both data types can be transferred synchronously or asynchronously. The format of the packetized data can be either simple 48-byte blocks or fully formatted ATM Cells.

Data delivery An SFODB network supports both circuit switched and packet switched data delivery services. These services may be mixed on the same SFODB network. Both services use multicast as the primary means of data transfer so that data destined for multiple FBIUs is transmitted only once.

*Data throughput*The SFODB network is scalable to allow the network to be optimized to meet specific spacecraft data throughput requirements. The network elements are scalable to accommodate a node-to-node data throughput rate of 200 Mbps to 1 Gbps.

Bandwidth reuse In a structured spacecraft architecture, the data handling capacity of an SFODB network can be multiplied several times by utilizing the SFODB's Bandwidth Reuse feature. Bandwidth Reuse simply means that once data reaches the destination FBIU the bandwidth used to transport that data can be immediately reused by the destination FBIU or any succeeding FBIU.

Deterministic latency Another key feature of an SFODB network is the deterministic nature of the data transfer latency. The data transfer latency on an SFODB network is deterministic and stable to within one byte. This is a product of the fixed-length frame format and the Latency Adjust Buffer (LAB) within the CFBIU.

Data transfer options The SFODB network offers the user several methods of transferring data between FBIUs. In fact, the ability to transfer both synchronous and asynchronous data, using either dedicated or token arbitrated bus bandwidth, in either a circuit switch or packet switch network configuration, can present a confusing set of options. However, all combinations of data transfer methods available on an SFODB network can be simplified into two methods of sending data and two methods of receiving data.

Sending data Network bandwidth is allocated by assigning one or more of the 32-Slots of an SFODB Frame to each of the FBIUs. These Slots can be either dedicated to a specific FBIU or shared between multiple FBIUs. When Slots are dedicated, the FBIU can insert data onto the network each time the assigned Slots rotate pass the FBIU. When Slots are shared, the FBIUs utilize token passing to arbitrate access to the assigned Slots with other FBIUs. The Dedicated Transmit Slot process is primarily intended for the transmission of continuous, high rate sensor data. The Token Arbitrated process allows multiple sources to efficiently share one or more Slots on the bus. Both transmit processes are broadcast in nature. Slot assignment is dynamically managed by the Control Host using the SFODB Subframe OH allowing real time bandwidth management without reducing data throughput.

Receiving data The broadcast data is accepted or rejected using either a Dedicated Receive Slot process or a ATM Header Addressed process. The Dedicated Receive Slot process supports the circuit switched method of data transfer. The ATM Header Addressed process supports the packet switched method of data transfer. The latter allows an SFODB network to function in a limited capacity as a distributed ATM switch. The data acceptance criteria is based on receive masks that define the Slots to be examined and VPI/VCI addresses to be accepted. Like the transmit Slot assignments, the FBIU receive masks are dynamically managed by the Control Host using the SFODB Subframe OH.

Data Host/FBIU interface Each FBIU provides its Data Host with full SFODB send and receive data access through two independent interface ports. Both ports are capable of transferring data in either ATM Cell format, 48–byte format or as continuous, unformatted data. The use of the ATM Cell format as the data transfer format on an SFODB network insures compatibility with ATM ground based communications networks and ATM compatible test equipment. However, since sensor data is not normally in ATM format, the FBIU send data port accepts continuous, unformatted data and builds an ATM Cell for transfer on the SFODB network. The FBIU receive data port can either output data in ATM format or strip the ATM Cell header and output the data as continuous, unformatted data.

Management layer characteristics

The SFODB Management Layer services require the participation of both the Control Host and Data Hosts. The primary element of control resides with the Control Host. The Data Host is limited to FBIU redundant element selection.

The CFBIU serves as the control and status interface between the Control Host and the SFODB network. The CFBIU provides the services required for network configuration, network synchronization and status reporting. These services are controlled and managed by the Control Host and executed by the CFBIU.

The SFODB Network Layer functions are considered part of the Management Layer services. Network bandwidth allocation and data routing services are established by the CFBIU based on configuration commands from the Control Host. In other words, the allocation of network bandwidth to specific FBIUs and the data routing map that defines the transfer of data between FBIUs is established by the Control Host using the FBIU configuration tables. These tables are generated by the Control Host, downloaded to the CFBIU and distributed by the CFBIU to the FBIUs. All network connections are established and broken using this methodology.

The following is a simplified overview of the SFODB network control services by briefly describing a power-up initialization sequence.

Redundant element selection Prior to power up, each Control Host and Data Host selects either the primary, cross-strap or bypass transmitter and receiver pair. As spacecraft power is applied to each Control Host and Data Host the host supplies power to one of the redundant CFBIU or FBIU elements.

Power up & synchronization Upon application of power the CFBIU automatically initiates the network synchronization sequence by the continuous transmission of a Synchronization Frame. As each FBIU in the ring establishes bit and frame synchronization, the FBIU allows the Synchronization Frame to pass through to the next FBIU. The receipt of the Synchronization Frame by the CFBIU signifies that network synchronization is complete. All FBIUs have established bit and frame synchronization and all FBIUs are online and ready to receive configuration commands from the CFBIU. If synchronization is lost during normal operation, the CFBIU automatically initiates this process in an attempt to reestablish network synchronization.

FBIU configuration Once SFODB network synchronization is complete, the CFBIU sets a flags indicating to the Control Host that it is ready to accept the FBIU bandwidth allocation and data routing tables. The CFBIU is capable of accepting these tables as individual commands from the Control Host or automatically sequencing through these commands in DMA mode.

As the CFBIU receives the FBIU configuration tables it transfers the data to the appropriate FBIU using the SFODB Subframe Overhead built into the network's 32-Slot frame. Each time a configuration command is sent to an FBIU the CFBIU automatically polls the FBIU to verify that the command was received and implemented correctly.

Normal mode Once network initialization and the configuration of all active FBIUs is completed, the CFBIU notifies all FBIUs that data transfer may commence. During this normal data transfer mode, the CFBIU monitors the operation of the network & generates statistical network performance reports. While in this mode the configuration tables for any FBIU can be modified. This allows the Control Host to dynamically reconfigure the SFODB network at any time.

What benefits does SFODB offer to the space community?

SFODB is an on-board payload data handling network based on an IEEE approved standard with capabilities that are orders of magnitude greater than those in existence today. It will do for high bandwidth, payload data handling applications what AS 1773 has done for Command & Telemetry applications - *Significantly reduce spacecraft development cost and development time*.

Tailored Protocol Unlike other approaches that attempt to adapt a existing protocol that was designed for point-to-point or computer-to-peripheral applications, the SFODB protocol was specifically designed to support the real time, high data throughput requirements of Remote Sensing spacecraft. That means:

- true real time capability
- minimum & deterministic latency
- minimum overhead
- minimum complexity
- no bells & whistles
- maximum reliability

Standard Interface One of the most time consuming, costly and risk intensive areas of spacecraft development is the specification, design, implementation and verification of the unique, special purpose, subsystem interfaces. It is froth with over specification, misinterpretation, over zealous verification and the subject of most design reviews and technical meetings. Eliminate the unique, special purpose, subsystem interfaces and you eliminate significant program development time, cost and risk. SFODB provides a simple, proven subsystem interface that is specified and controlled by and IEEE standard.

ATM Data Format Okay, now that I have this gigabit data stream coming out of my spacecraft, how do I get it to the users? It would be nice if I didn't need to develop a costly, one of a kind, piece of equipment to reformat the data in order to interface with a commercial telecommunications network. It would be really nice in the future if I could interface directly with commercial telecommunications satellites. *SFODB is compatible with the commercial ATM telecommunications standard*. SFODB accepts and outputs data in standard ATM cell format. For backward compatibility with existing subsystems, SFODB accepts raw, unformatted data streams and formats the data into ATM cells. SFODB even uses the ATM Header information to control the data routing within the SFODB network.

Reliability Network and protocol standards developed for the personal computer industry and instrumentation industry do not really address the redundancy issue that is vital to spacecraft reliability. Redundancy adds cost, complexity and is an unnecessary feature in these commercial applications. These commercial applications are also unconcerned about natural radiation tolerance. Therefore, the commercially available devices do not address this other vital spacecraft reliability issue. The currently available SFODB components were designed specifically to be radiation tolerant. The CMOS devices are fabricated in Honeywell's QML RICMOS VI technology and the GaAs devices are fabricated in Honeywell's low power, radiation tolerant CHFET technology. The SFODB architecture implements a redundant, cross-strap topology with an additional node bypass feature that can be used as an additional level of redundancy or as a power management feature.

Flexibility Spacecraft command and telemetry subsystems have long since adopted the plug and play flexibility of Mil-Standard 1553 and SAE 1773 networks. However, spacecraft payload data handling subsystems continue to rely on special purpose, one of a kind implementations. As a result, changes in spacecraft payload configuration and/or sensor mix requires a costly redesign of the special purpose data handling subsystem. SFODB offers open architecture payload plug and play flexibility with a multi-gigabit data handling capability.

This enables a spacecraft platform to accommodate a variable sensor mix without a costly and risky data handling subsystem redesign.

It enables the independent evolution of subsystem technology and capability, eliminating the cost and risk associated with upgrading inter-dependent subsystems.

It enables the development of a standard set of system and subsystem test equipment eliminating the cost and risk associated with special purpose integration and test equipment.

Who sponsored SFODB and why?

NASA GSFC and DoD co-sponsored the development of SFODB to reduce the cost and risk of future spacecraft development by providing a flexible, payload data handling network, defined and sanctioned by credible standards organization.

Application perspective

The bandwidth and resolution of aerospace remote sensing payloads continues to advance, placing ever increasing demands on onboard data handling networks. At the same time economics and rapid development requirements are driving onboard data handling networks toward flexible, non-proprietary architectures and interface standardization. These characteristics are extensively addressed in existing ground based networks. However, unlike most ground based networks designed primarily to support the transfer of non-real time data between computers, an onboard data handling network must support the real time needs of the aerospace remote sensing environment.

Network perspective

Aerospace remote sensing data is characterized by synchronous components, common to continuous mode sensors, and asynchronous components, common to event driven sensors. Both sensor types have real time data handling requirements and sensor performance is driving data bandwidth requirements into multiple gigabit per second range. Even at these higher data rates, aerospace systems will continue to be constrained by size, weight and power limitations. In order to achieve high data rate performance while maintaining low size, weight and power, on-board data handling subsystems must employ highly integrated components and must avoid the higher layer protocol features commonly found in ground based networks. Furthermore, space based data handling networks must be fault tolerant and able to withstand the rigors of launch and the harsh space environment.

Adaptation of existing ground based network standards is not practical because of insufficient bandwidth and high power dissipation. Also, conversion of current implementations to space qualifiable processes is not feasible. Therefore, a new on-board data handling network standard for aerospace remote sensing applications is necessary.

Technology perspective

Fiber optic and ASIC technologies have matured to the point that multiple gigabit data handling networks for aerospace applications are practical. Fiber optics technology is especially appealing because of its extremely high bandwidth capacity. Multimode fibers have been demonstrated to be radiation hard with negligible increase in signal loss over a ten year life in space radiation environments. Space qualifiable connectors have been designed and built specifically for fiber cable. Techniques for low loss termination and coupling of fibers have been perfected. High power laser diodes capable of operation over a wide temperature range and low noise optical receivers are now available. State-of-the-art semiconductor materials and processes as well as packaging techniques are leading towards smaller, faster, and lower power devices that will enable high-speed data handling systems for space applications.

Who Developed SFODB?

Orlando & Associates, Inc. (OAI) lead the definition and development of the SFODB Architecture and Protocol and the development of the IEEE 1393-1999 standard.

TRW & Honeywell developed SFODB ASICs and the SFODB MCMs.

Space Photonics, Inc. (SPI) developed the Parallel Physical Layer Transmitter and Receiver MCMs.

OAI, Broadband Communications Products (BCP) and TRW developed the Development & Test System.

What SFODB products are available now?

There are two implementations of the SFODB available today - the Serial SFODB and the Parallel SFODB. Both use the same SFODB Protocol ASICs but differ in Physical Layer implementation. Both implementations are functionally identical and transparent to the user.

The Serial SFODB implementation complies fully with the SFODB Physical Layer standards and each MCM provide primary, cross-strap and bypass transmit and receive fibers.

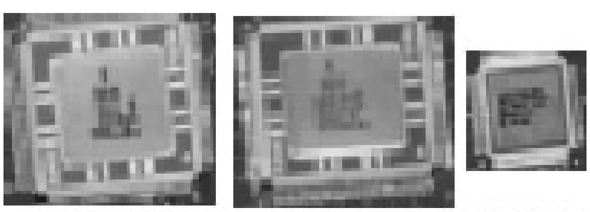
The Parallel SFODB implements a 12-channel, fiber optic ribbon cable Physical Layer. The 12-channel ribbon contains 8 data channels, a byte clock channel, a frame sync channel and 2 backup channels which provide redundancy for the primary 10 channels.

Protocol ASICs

There are three currently available Protocol ASICs:

- CFBIU Protocol ASIC
- FBIU Protocol ASIC
- Dual Port RAM ASIC

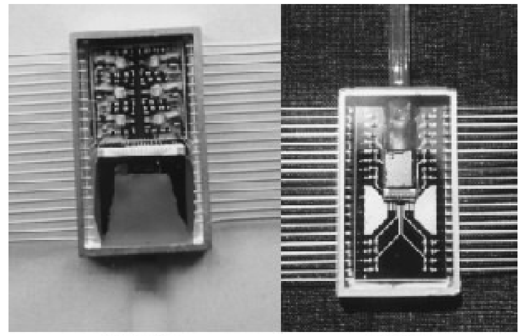
These ASICs are implemented in Honeywell's QML RICMOS VI CMOS technology and are available from both TRW and Honeywell as either die or packaged parts.



CFBIU ASIC FBIU ASIC DPRAM

Parallel SFODB Physical Layer Devices

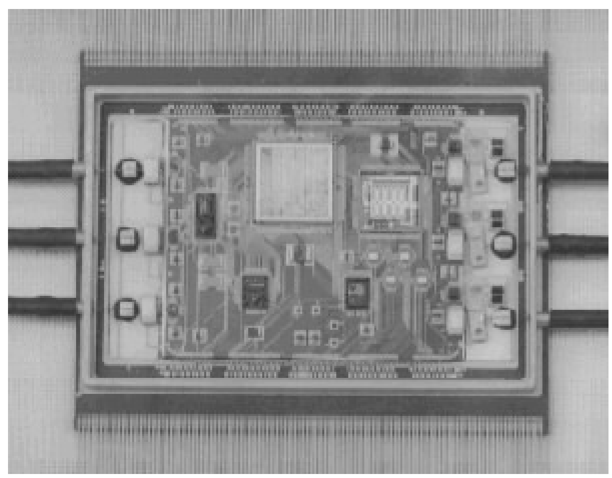
The Parallel SFODB Transmitter (PFOTX) and Receiver (PFORX) MCMs are available from Space Photonics, Inc.



PFORX PFOTX

Serial SFODB Physical Layer Devices

The Serial SFODB MCM package and substrates have been developed and demonstrated, and are available from TRW. Second generation CHFET devices have been fabricated and tested at the wafer level but have not been integrated into the MCMs and tested. The CHFET devices should be available soon from TRW and Honeywell as unpackaged die. Once the CHFET ASICS have been fully integrated and tested at the MCM level, the Serial SFODB MCMs will be available from TRW.



Development & Test System

A Development & Test System that can be used for training, flight software development and subsystem testing is available from Space Photonics, Inc. The Development & Test System consists of a desk top PC with an additional LabVIEW DIO card and LabVIEW software, a VXI extension chassis, and one each CFBIU and FBIU card.

What near term SFODB products are in process?

SPI is currently developing a set of Serial SFODB Transmitter and Receiver MCMs to support an SFODB implementation with packaged parts or a chip on board implementation.

Litton Amecom and SPI are jointly developing single chip implementations of the CFBIU Protocol ASIC and the FBIU Protocol ASIC. Both devices will be fabricated in Honeywell's Rad-Hard SOI CMOS technology.

SPI is also developing a Serial SFODB version of the CFBIU and FBIU card for the Development & Test System.

What future SFODB products are planned?

There are two R&D efforts in process at Space Photonics, Inc. and Orlando & Associates, Inc. to increase the data handling capacity of the SFODB network.

The first project will increase the data rate of the Serial SFODB implementation to OC-48 (2.488 Gbps) and then to OC-96 (4.98 Gbps).

The second project will develop a Stacked Ring topology for the SFODB. The first step will be to increase the data rate of the current SFODB network to OC-192 (9.95 Gbps). The second step will develop the optical devices necessary for the Stacked Ring implementation. The Stacked Ring implementation will be scalable from four to at least twelve rings. This will allow SFODB network implementations with data handling capacities ranging from 40 Gbps to to 120 Gbps.

What support is needed from Government and Industry?

If the Government and the Aerospace Industry are serious about reducing spacecraft development time, risk and cost then SFODB needs support, sponsorship and partners. At every conference we hear great speeches on the need for "*faster, better, cheaper*" spacecraft development. However, to date the Aerospace Community continues to focus on the development of proprietary, closed architecture spacecraft and subsystems. If the Computer and Aircraft Industries have taught us anything, it is that this is not a winning approach in a maturing industry. The better way to reduce development cost, time to market and to provide "*faster, cheaper, better*" spacecraft is to embrace an open architecture with standardized interfaces. SFODB fills this need.